SPACE SHUTTLE COMMUNICATIONS AND TRACKING SYSTEM

By BARTUS H. BATSON and JOHN H. JOHNSON
Lyndon B. Johnson Space Center
Houston, Texas

SUMMARY. This paper provides an overview of communications and tracking for the Space Shuttle Program. The Shuttle Program itself is briefly described, and communications and tracking requirements and capabilities are discussed for the various phases (ascent, on-orbit, and reentry/ landing) of a Shuttle mission.

INTRODUCTION. The primary objective of the Space Shuttle Program is to provide an economic space transportation system that will support a wide range of scientific, defense, and commercial applications in Earth orbit. The Shuttle will be a manned, reuseable space vehicle designed to accommodate these applications. As shown in figure 1, it will consist of two stages, the first being an unmanned booster rocket and the second being piloted such that it can be flown back to Earth for an airplane-like landing Two launch sites are planned for the Shuttle Program: Kennedy Space Center (KSC) and Vandenberg Air Force Base (VAFB). Five landing sites are currently being assumed for planning purposes: KSC, VAFB, Edwards AFB, Anderson AFB (in Guam), and Hickham AFB (in Hawaii).

The manned Orbiter will be approximately 108 feet long and will have a wingspread of 78 feet. It will be capable of carrying a payload of 65,000 pounds. The crew will consist of two pilots and two flight engineers. The duties of the latter include checkout and deployment of unmanned satellite payloads.

The Shuttle Orbiter will be used to carry into space nearly all civilian and military payloads of the future, including automated scientific space probes and Earth-orbiting solar and astronomical observatories. Application payloads will be Earth resources sensing, communications, meteorological, and geodetic satellites.

The major program milestones for Shuttle are summarized in figure 2. Current estimates are for the Shuttle to carry out 30 to 40 missions per year, with a mission mix of 30 percent for the Department of Defense (DOD) and the remainder for others. Approximately 80 percent of the total flights will be for deploying and servicing satellite payloads.

COMMUNICATIONS. The Shuttle Orbiter will have several communications links, depending on the particular type of mission involved and depending on the mission phase.

Ascent. During ascent, the Shuttle must communicate with ground-based terminals, either the Space Tracking and Data Network (STDN) for NASA missions or the Satellite Control Facility (SCF) for DOD missions. As illustrated in figure 3(a), there will be an S-band uplink (PM) available. This link will be used for transmission of voice (two 32-kbps delta-modulated channels) and commands (encoded to 6.4 kbps and added to a 1.6-kbps synchronization signal). The resulting TDM (time-division-multiplexed) uplink data rate will be 72 kbps. There will also be a PM/PM subcarrier containing transmitted range tones (for coherent turnaround in the Orbiter transponder). The uplink carrier frequency will be either 2041.947 MHz or 2106.406 MHz for NASA missions; for DOD missions, the uplink frequency will be either 1775.733 MHz or 1831.787 MHz.

The S-band downlink (PM) available for communications during ascent will be used for transmission of voice (two 32-kbps delta-modulated channels) and PCM (pulse-code-modulated) telemetry (128 kbps) for a resulting TDM data rate of 192 kbps. The uplink PM/PM range tone subcarrier will be coherently turned around and retransmitted as part of the downlink signal. The downlink carrier frequency will be 240/221 times the uplink frequency for NASA missions or 256/205 times the uplink frequency for DOD missions and will nominally be either 2217.5 MHz or 2287.5 MHz for either class of mission.

Both the S-band PM uplink and downlink will utilize a system of four flush-mounted, switchable, omnidirectional Orbiter antenna elements. There will be another S-band downlink (FM) available for ascent communications. This link, which will utilize a separate system of two flush-mounted, switchable omnidirectional antenna elements, will be designed primarily for onorbit support of television, wideband payload data, or playback of recorded Orbiter data. However, during ascent this link will be available for realtime transmission of Orbiter main-engine data [three separate 60-kbps digital signals each used to phase-shift-key (PSK) a separate subcarrier]. There is also the possibility that for certain DOD missions this link will be used for transmission of 256-kbps payload data so that ground monitoring of critical payload parameters may be accomplished. A carrier frequency of 2250 MHz will be used for the FM direct downlink, with an available RF bandwidth of 10 MHz.

On-Orbit. As illustrated in figure 3(b), during on-orbit operation the Shuttle Orbiter must communicate with ground stations, either directly or via a tracking and data relay satellite (TDRS) system. The direct ground links will be exactly the same as for ascent (S-band PM uplink and S-band PM and FM downlinks), except that the absence of a requirement for turnaround ranging will allow the ranging signal to be turned off. The FM downlink will be used for time-shared transmission of television (NASA missions only), 1:1 playback of recorded operational data (128 kbps), 8:1 playback of recorded operational data (8 x 128 kbps = 1.024 Mbps), wideband digital or analog payload data, or 256-kbps secure payload data (DOD missions only).

The S-band relay links (NASA use only) will be similar to the S-band PM direct links, with several very significant exceptions (all being required to alleviate performance problems associated with the relay links). As illustrated in figure 4, the TDRS system (two geosynchronous satellites, 130° apart) will provide a very high coverage capability. This increased coverage, however, will not be without penalty. Using a switched-element, omnidirectional, flush-mounted antenna system on the Orbiter for communications with a 12.5-foot dish at distances in excess of 22,000 nautical miles will result in very weak links. As a consequence of this, it has been necessary to baseline a coded PSK signal design[1] for both the forward (ground→TDRS→Orbiter) and return (Orbiter→TDRS→ground) links, together with a high-power (~100-watt) transmitter power amplifier and a low-noise receiver. In addition, it has bAn necessary to provide for a reduced data-rate forward link mode consisting of two 16-kbps delta-modulated voice channels and 8 kbps of encoded commands plus synchronization for a total of 40 kbps; a reduced data-rate return link mode will also be available, providing two 32-kbps delta-modulated voice channels and 64 kbps of PCM telemetry, for a total of 128 kbps. The reduced rate modes will only be used for relay transmission and not for the direct ground links.

In addition to the S-band direct and relay links, the capability for relay of wideband signals via TDRS over K_u-band forward and return links is planned. Preliminary sizing studies have assumed for the return link either (a) high-rate digital data (up to 50 Mbps) plus operational data/ voice (192 kbps) or (b) television plus high-rate digital data (1 Mbps) plus operational data/voice (192 kbps) over the return link; for the forward link, there will be a capability for digital data (probably 1 Mbps) plus operational commands/voice (72 kbps). The K_u-band relay links will timeshare the deployable 20-inch steerable antenna used by the Orbiter rendezvous radar; whenever this antenna is deployed and the K_u-band relay links are established, the S-band links will no longer be used for transmission of operational data/commands/voice.

Figure 3(b) also indicates that the Orbiter will communicate with either NASA or DOD payloads. This capability is required at relatively close ranges (<10 n.mi.) to facilitate post-deployment checkout or preretrieval safing and/or checkout of payloads. (The capability is also required to communicate with attached payloads--predeployment or postretrieval.) Communications with released payloads will be via an S-band link. The Orbiter will transmit commands (plus voice, if the payload is manned) to the payloads, and the payload

[1] Batson, B. H., and R. W. Moorehead, "A Digital Communications System for Manned Spaceflight Applications," Proceedings of the 1973 International Conference on Communications, Seattle, Washington, pp. 37-1 to 37-9.

will transmit PCM telemetry (plus voice, if manned) back to the Orbiter. The Orbiter payload interrogator will be designed to receive any of 20 channels (5-MHz each) located in the 2200- to 2300-MHz band, and to transmit at either 221/240 times the receive frequency (for NASA payloads) or 205/256 times the receive frequency (for DOD payloads). A single flush-mounted Orbiter antenna will be used for communications with payloads. Figure 5 shows the frequency plan for Orbiter/ payload communications. An interesting design problem is introduced by the fact that it may be necessary for the Orbiter to simultaneously transmit to ground or TDRS and receive from payloads in either the same channel or in nearby channels. The filtering necessary to properly isolate the payload receiver (in the Orbiter) from the ground/TDRS transmitter (in the Orbiter) thus becomes very critical and very difficult to achieve.

The remaining communications capability required during on-orbit operations is between the Orbiter and either one or two extravehicular (EVA) crewmen. It will be necessary for the Orbiter to transmit voice to the crewmen and to receive voice and biomedical data. Both units of a redundant UHF transceiver (also used for communications with air traffic controllers during reentry/landing) can be activated to obtain duplex operation with the crewmen, or the units can be activated individually for simplex operation. The Orbiter transmit frequency will be 296.8 MHz, with a transmit bandwidth of 55 kHz, and will be the same for all modes of operation. The transmit frequency of the first crewman (EVA_1), will be 259.7 MHz, with a transmit bandwidth of 55 kHz. The transmit frequency of the second crewman (EVA_2) will be 279.0 MHz, with a transmit bandwidth of 100 kHz to allow for relay of EVA_1 voice/data to the Orbiter.

Reentry/Landing. Figure 3(c) indicates the Orbiter communications capabilities required during reentry and landing. After RF blackout, the Orbiter must communicate with either the STDN or the SCF. The S-band PM direct uplink and downlink, exactly as described for ascent communications, will be utilized. Although the capability will exist to use the S-band FM direct downlink, no requirement for its use is foreseen at this time.

In addition to communicating with the STDN or the SCF, the Orbiter will also be required to communicate (voice only) with air traffic controllers (ATC) and it is desired to have the capability for communicating (voice only) with chase planes. These capabilities will be provided by the UHF ATC transceiver, which has 7000 AM voice channels spaced 25 kHz apart in the 225.000- to 399.975-MHz frequency band.

TRACKING. There are several tracking functions associated with a Shuttle mission, some of which will involve the Orbiter as the target (the object being tracked), and some of which will utilize systems onboard the Orbiter to track other vehicles/terminals.

Ascent. Figure 6(a) indicates the basic tracking function required during the ascent phase of a Shuttle mission. As pointed out previously in the discussion of ascent communications, the S-band PM uplink signal from STDN or SCF will contain a subcarrier which is phase-modulated by a set of range tones. This modulated subcarrier will be turned around coherently in the Orbiter transponder and the received tones at the ground station will be compared with the transmitted tones such that a phase measurement, directly relatable to two-way range between ground station and Orbiter, is obtained. This range measurement will then be used on the ground to develop trajectory data which are independent of Orbiter onboard measurements and/or computations.

On-Orbit. During on-orbit operations, as indicated in figure 6(b), Doppler extraction will be achieved both onboard the Orbiter (one-way Doppler) and at the ground (two-way Doppler) for either S-band direct or TDRS-relay transmission, using the PM communications carrier. One-way Doppler extraction is based on comparing the frequency of the Doppler-shifted carrier received at the Orbiter with the frequency of a very stable (1 part in 10^{10} over a 1-second interval, 1 part in 10^{9} over a 24-hour interval) onboard reference oscillator to determine a relative velocity measurement. This measurement can then be integrated to obtain range, which will be used by the Orbiter G&N (guidance and navigation) system to determine a state vector. An alternate method of computing a state vector is to use two-way Doppler (which is based on comparing the ground station transmit frequency with the frequency of the Doppler-shifted coherent carrier received at the ground station). The computation can be performed on the ground and the resultant state vector transmitted to the Orbiter via the uplink or forward link command channel.

Another tracking function which will be required during on-orbit operations is that of payload tracking by the Orbiter. In order to accomplish station-keeping (either post-deployment or pre-retrieval) or rendezvous with orbiting satellites, measurements of range, range rate, angle, and angle rate will be required. Targets may be either cooperative (having a transponder which will retransmit the signal received from the Orbiter radar) or passive (requiring “skin-track” by the Orbiter radar).

The basic requirements imposed on the rendevous radar are for a range measurement (accurate to within ±1%) from 10 nautical miles to 100 feet, a range rate measurement accurate to within ±1 ft./sec., an angle measurement having a ±10 mr random error and 60 mr bias error, and an angle rate measurement accurate to within ±0.14 mr/sec. Those characteristics of the radar which impact the structural and electronic interfaces in the Orbiter have been preliminarily defined; however, the specific radar mechanization has not been selected. The radar antenna (also shared for K_u-band relay communications) will be a 20-inch boom-deployable, Cassegranian-feed parabolic dish operating nominally at 15 GHz. Angle tracking will be accomplished via a 4-horn monopulse scheme. The radar average transmit power is planned to be 40 watts.

Reentry/Landing. Figure 6(c) shows that in addition to S-band turnaround ranging, several tracking functions are required which are uniquely related to the reentry/landing phase of a Shuttle mission. Area navigation will be accomplished using TACAN (tactical air navigation). A system of three airborne TACAN receiver/transmitters with demodulation, decoding, and data computation capabilities will provide the Orbiter crew and guidance system with slant range and direct magnetic bearing to groundbased TACAN beacons. Each of the airborne TACAN navigational units will interface with two antennas (L-band annular slots, one top and one bottom) and an external computer which will automatically select the channel, antenna, and mode of operation, and which will display range and bearing information on a horizontal situation indicator (HSI). In addition, each unit will receive a periodic identification signal from the ground beacon and will provide an audio output signal to the Orbiter intercom system.

An autoland capability will be facilitated by two classes of onboard navaids, the MSBLS and the radar altimeter. The MSBLS (triply redundant RF units, receiver/decoder units, and K_u-band waveguide horn antennas) will provide guidance signals beginning at least 16 n.mi. from touchdown (or at least 10 n.mi., in 10 mm/hr. rainfall) and continuing through touchdown and rollout. The MSBLS ground station will provide azimuth and elevation data by means of two planar shaped beams which scan 20° either side of azimuth centerline and from 0° to 30° in elevation. These K_u-band beams will be pulse-code-modulated with the pointing angle information. The MSBLS airborne receiver will be illuminated sequentially by the azimuth-elevation beams 5 times per second and will transform the pulse coded information into azimuth and elevation angles. The MSBLS also will provide precision range-to-go information by means of an airborne K_u-band interrogator and a ground transponder located at the runway. When the Shuttle vehicle gets close to the ground, the azimuth and range data will remain good, but the elevation data will begin to degenerate. At this point, the C-band pulsed radar altimeter (dual redundant with dedicated transmit and receive waveguide horn antennas) will take over and provide the needed accuracy in altitude. The altimeter will be capable of operating with a high degree of accuracy from 2500 feet down to wheel touchdown. After touchdown the MSBLS azimuth and range data will provide steering and braking commands through rollout to a full stop. This will terminate autoland; taxi operation will be handled by a tow vehicle.

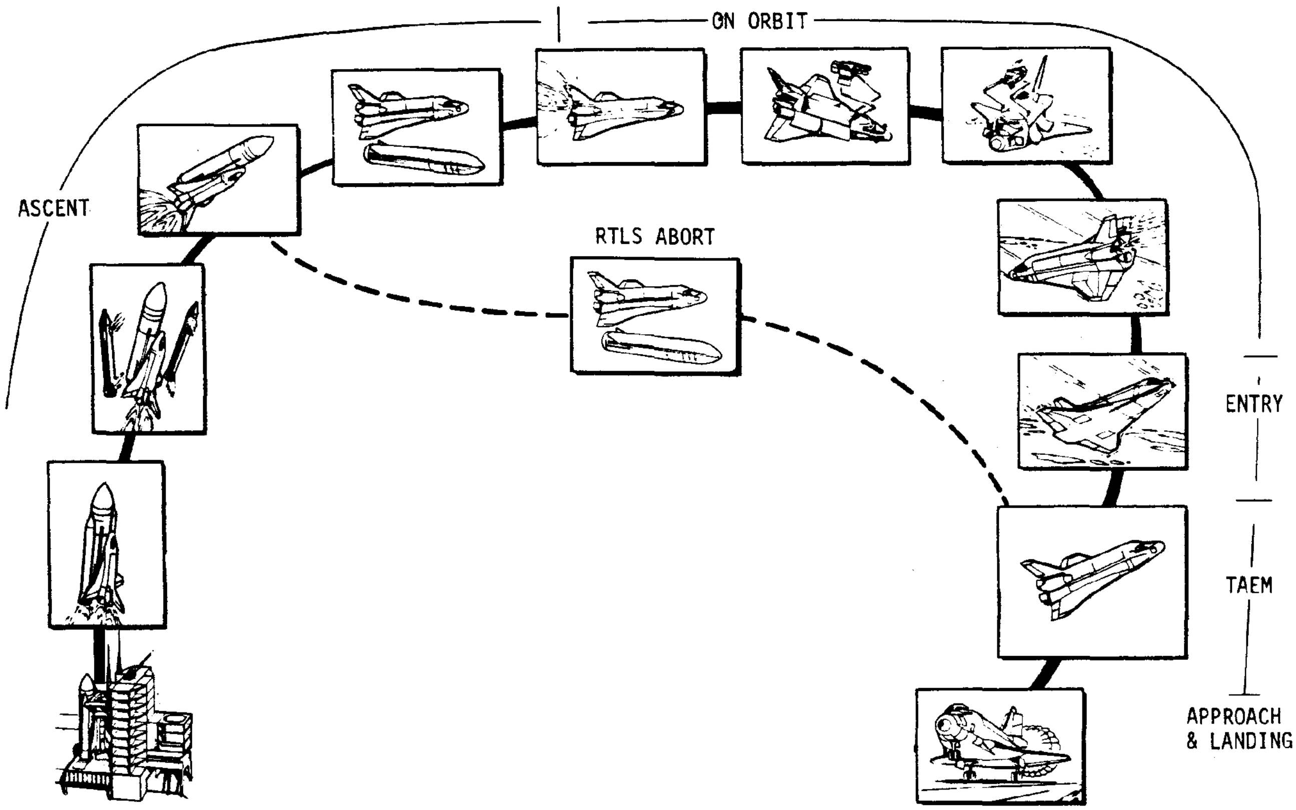


Figure l.- Shuttle mission profile

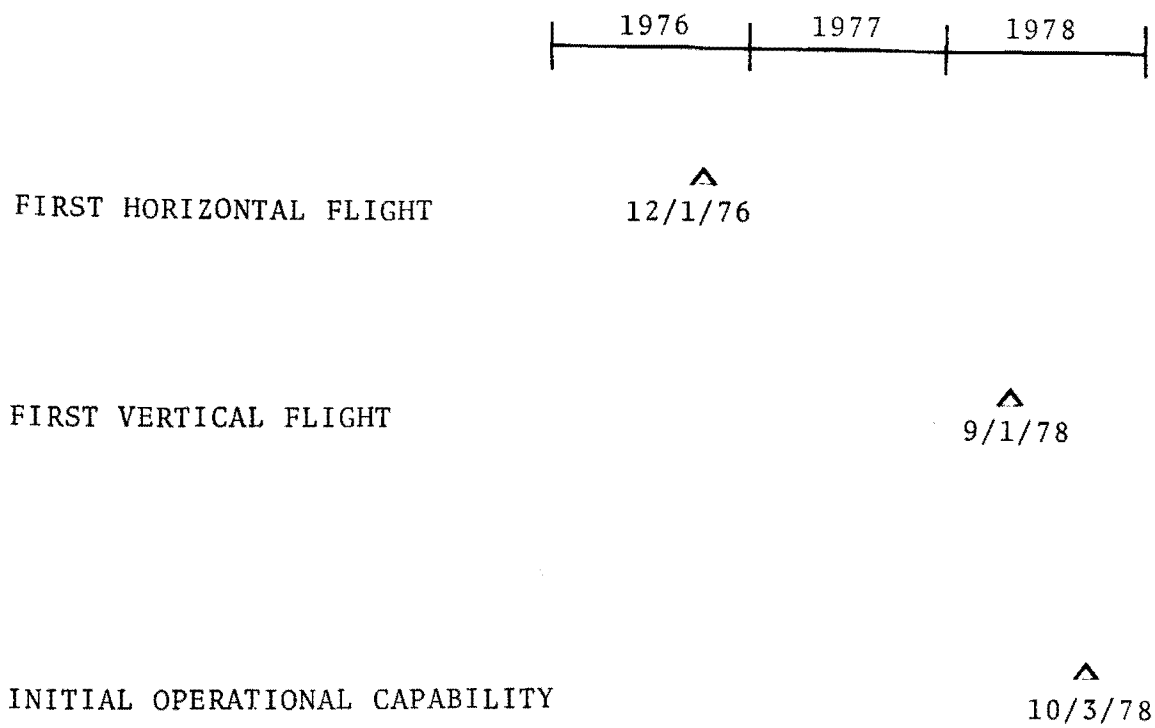


Figure 2.- Shuttle Program milestones

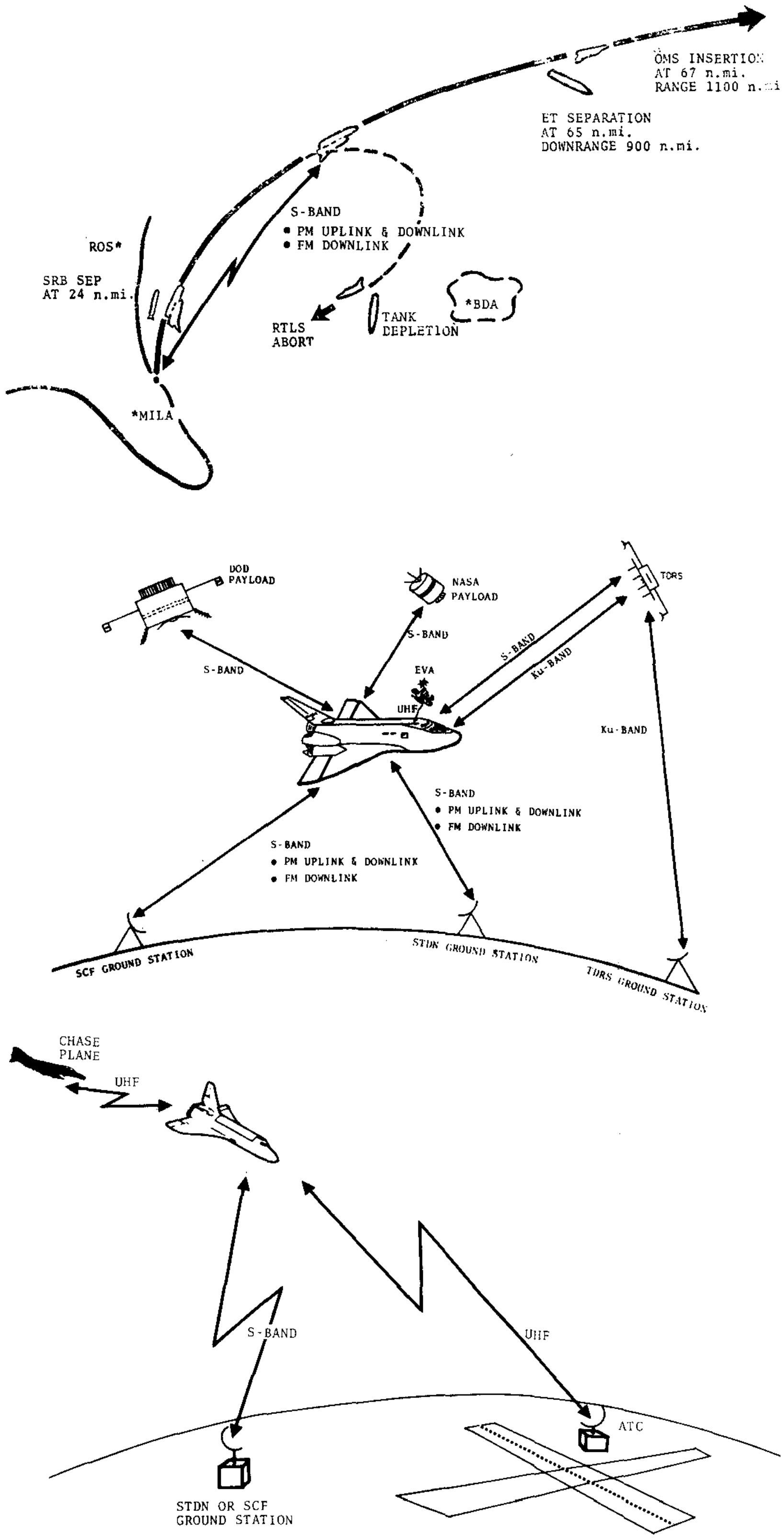
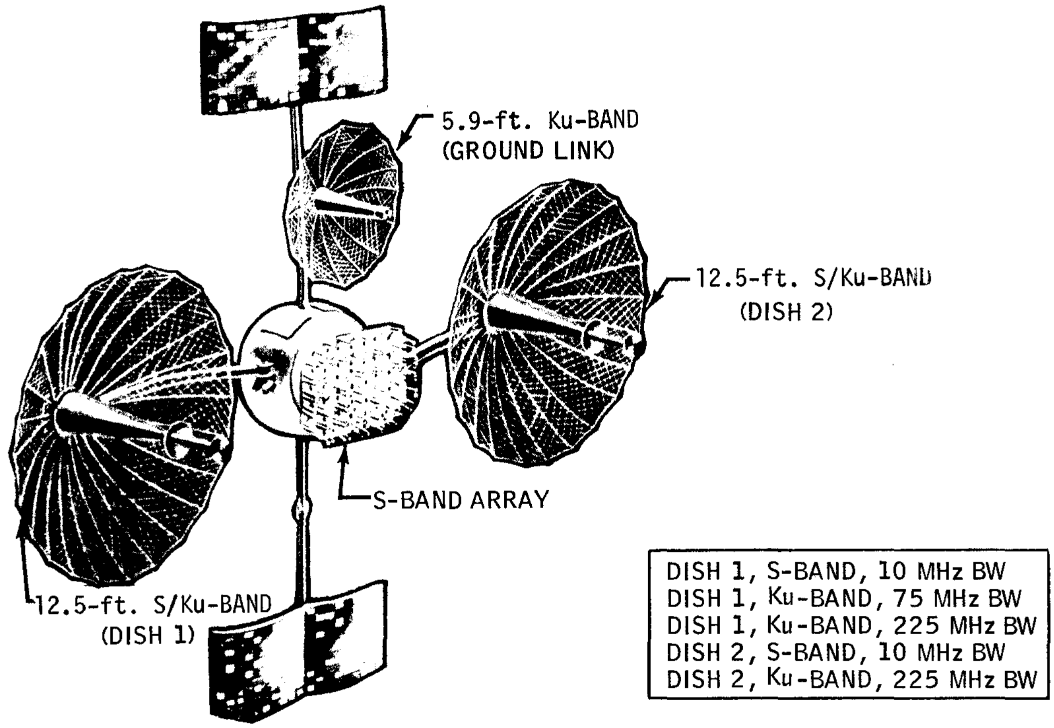


Figure 3.- Shuttle communications
(a) Ascent (KSC launch)
(b) On-orbit
(c) Reentry/landing



NOTE: S-BAND ARRAY IS FOR LOW DATA RATE USERS AND CAN HANDLE UP TO 20 SIMULTANEOUSLY. IT IS NOT UTILIZED BY SHUTTLE.

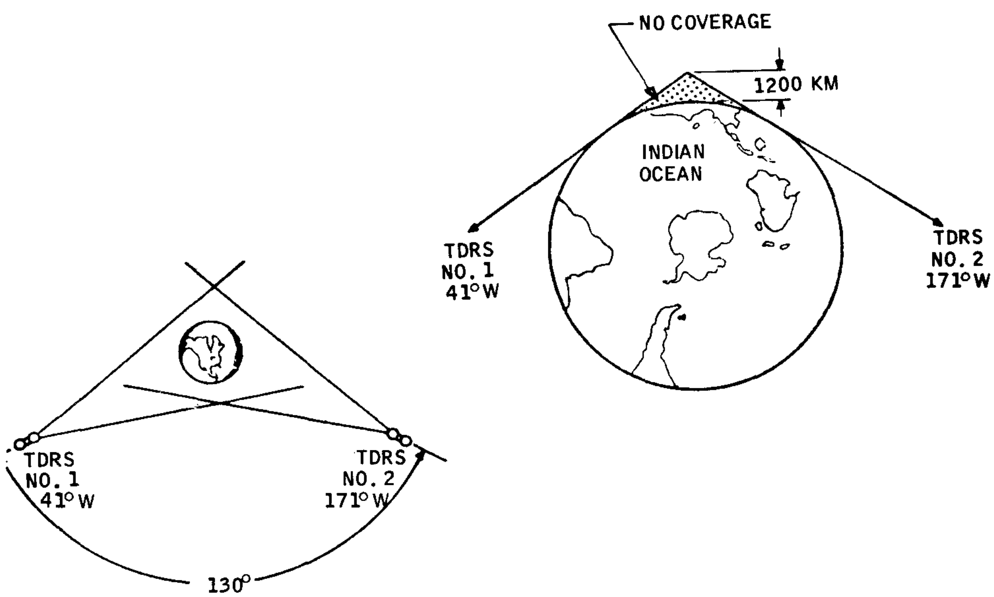


Figure 4.- Tracking and Data Relay Satellite System

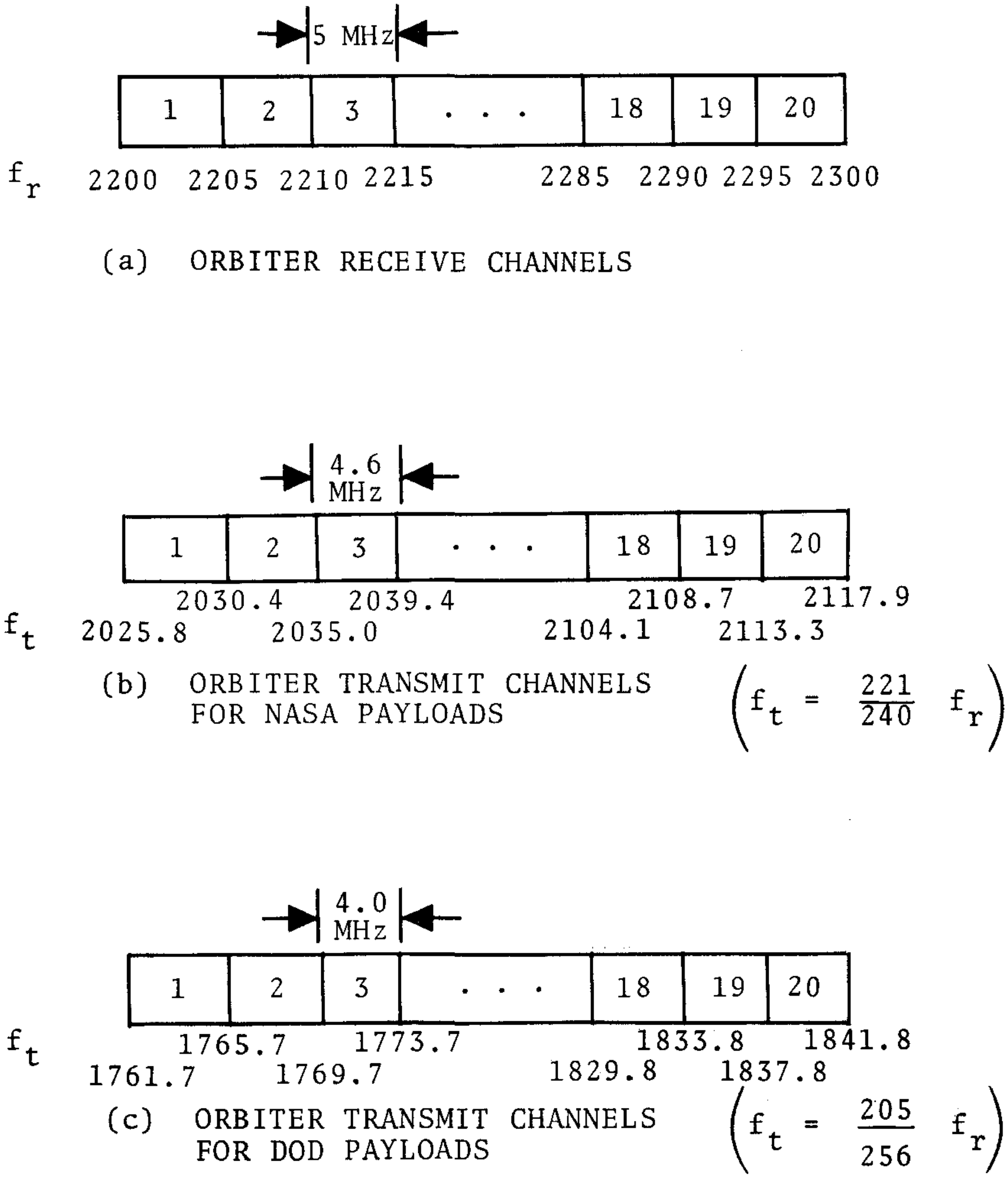


Figure 5.- (a) Satellite characteristics
(b) User coverage capability

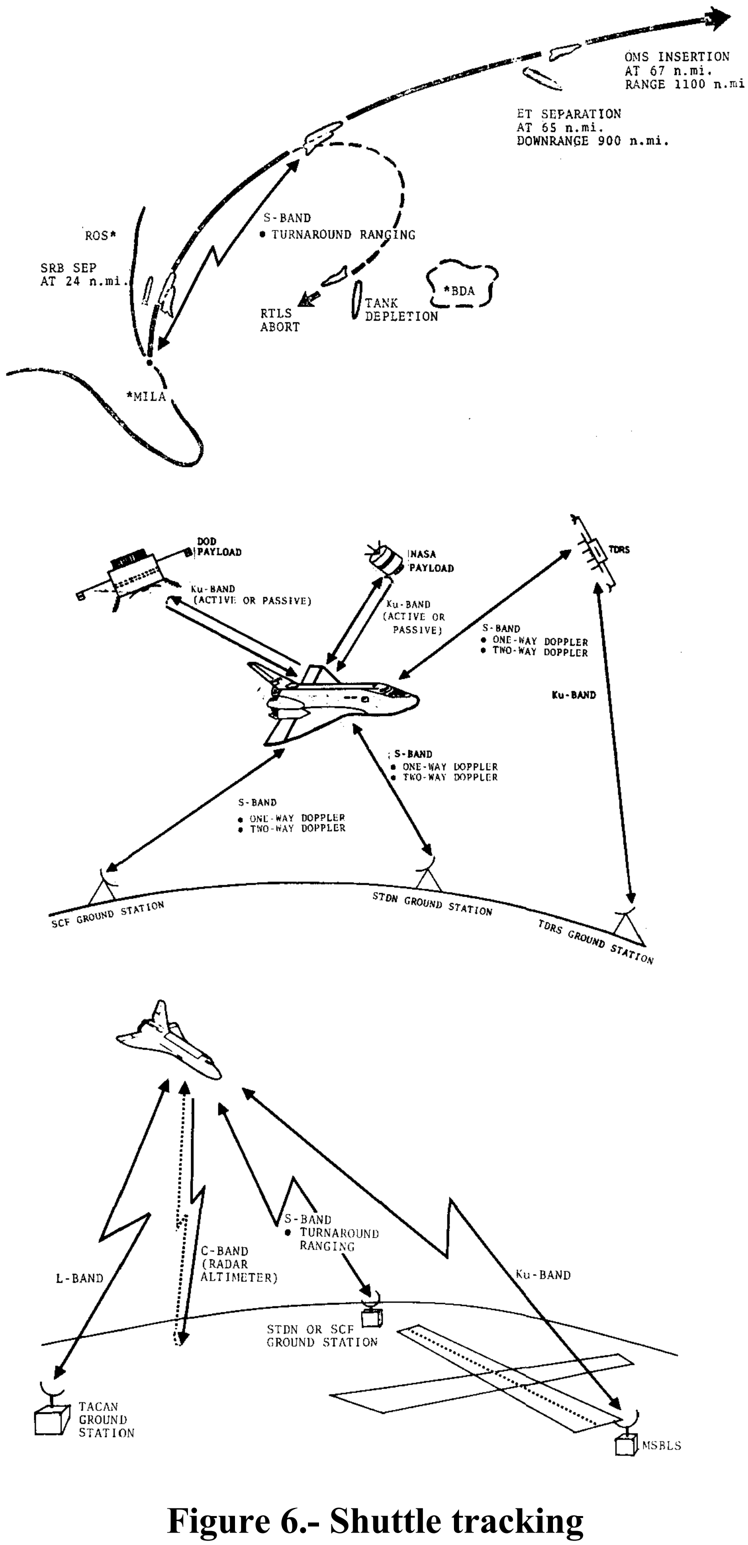


Figure 6.- Shuttle tracking

(a) Ascent (KSC launch)

(b) On-orbit

(c) Reentry/landing